Green Chemistry as Social Movement?

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Are there circumstances under which scientists and engineers doing their ordinary jobs can be thought of as participants in a social movement? The technoscientists analyzed in this article are at the forefront of a new way of doing chemistry; they are attempting to redesign chemical products and synthesis pathways to significantly reduce health effects and environmental damage from industrial chemicals. Green chemistry practitioners and entrepreneurs now constitute a small minority of chemists and chemical engineers in the university, government, and corporate sectors, but the innovators gradually are institutionalizing their efforts and winning converts. Drawing on concepts from social movement theory, the authors argue that examining green chemistry as a social movement sheds light on the intentional social organization of emerging scientific and engineering disciplines, advances thinking about the role of expertise in social change, and uncovers a possible pathway toward reconstructing chemical technologies on a more environmentally sustainable basis. The article closes with questions about potential coalitions among green chemists and engineers, regulators, and activist sectors of civil society.

Keywords: *green chemistry; social movements; expertise; environmentalism*

Might environmentally responsible technological innovation ever be *led* by technoscientists working within mainstream corporate, governmental, and university institutions? Could it be that the sociotechnical value shifts and reforms called for by many progressive scholars and activists—peace, sustainability, genuine democracy, and social justice—will remain oppositional and marginal unless such innovations take root and blossom in established institutions? If so, if building an environmentally commendable civilization requires a larger and more influential coalition than well-meaning outsiders to the technosphere usually can muster, there may be no substitute for enrolling insiders as enthusiastic actors and even leaders in the endeavor rather than as resentful and legally mandated participants. This

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article offers a preliminary examination of one small but potentially very important group of such insiders, those pursuing "green chemistry."

We inquire into whether it may be practically and theoretically useful to think of green chemists and engineers, and their activities and institutions, in terms of social movement theory. Social movements are organized networks whose members work within political opportunity structures while sharing identifiable discourses, ideologies, and strategies. There is significant historical precedent for expert participation in peace, antinuclear, public health, environmental, and other reform efforts, of course, but we think there may be some unique elements to the endeavor we have been studying.

The first section provides an overview of the field of green chemistry and introduces its founders, leaders, and institutions. The following section draws on concepts from social movement theory to analyze the developments in green chemistry. The third section probes some of the possibilities and problems that political progressives would face in trying to cooperate with green chemists. The conclusion links the analysis to more general questions concerning the governance of technological innovation, particularly those concerning the political roles of experts and expertise.

Green Chemistry: Recent Developments, Actors, and Institutions

What Is Green Chemistry?

As the name implies, advocates for green chemistry aim to make humanity's approach to chemicals—especially synthetic organic chemicals—environmentally sustainable. The focus is on the prevention of problems before they occur by (re)designing chemicals and chemical production processes at a molecular level.

With little controversy or publicity, in the past few years there has begun to emerge what could turn out to be a profound transformation in the methods, raw materials, by-products, and end products of chemical synthesis. An exaggeration that makes the point is to say that twentieth-century "brown" chemistry (and chemical engineering, and the chemical industry) proceeded according to the following "formula":

- Start with a petroleum-based feedstock;
- dissolve it;
- add a reagent;

- react the compounds to produce intermediate chemicals;
- put these through a long series of additional reactions
- to yield megaton quantities
- of potentially dangerous final products;
- release these into ecosystems and human environments without knowledge of long-term effects,
- without going through gradual scale-up to learn from experience; and
- in the process create millions of tons of hazardous wastes as by-products.

In contrast, green chemistry would do the following:

- Design each new molecule so as to accelerate both excretion from living organisms and biodegradation in ecosystems;
- create the chemical from a carbohydrate (sugar/starch/cellulose) or oleic (oily/fatty) feedstock;
- and rely on a catalyst, often biological,
- in a small-scale process
- that uses no solvents or benign ones
- and requires only a few steps,
- creating little or no hazardous waste as by-products;
- to yield small quantities of the new chemical for exhaustive toxicology and other testing,
- followed by very gradual scale-up and learning by doing.

The second chemical scenario may potentially be within the capacities of a revamped chemistry and chemical engineering, although the extent to which the chemical industry and its customers will embrace these technical potentials is not clear.[1]

The term *green chemistry* as normally used at present does not actually imply adherence to all the above attributes. Sometimes referred to as *sustainable chemistry*, the endeavor is billed as "promoting development of safer chemical production processes and products" via "cutting-edge research . . . designed to reduce or eliminate the use or generation of hazardous materials associated with the design, manufacture, and use of chemical products" (Gordon Research Conferences 2000). Standard topics include catalysis (homogeneous, heterogeneous, and bio-based), bio-based synthesis and processing, alternative synthesis pathways, green solvents and reaction conditions, and, more generally, safer chemicals and materials.

Although research is well ahead of practice, promising industrial applications are beginning to appear. For example, the manufacture of ibuprofen, the well-known painkiller sold as Advil™ and Motrin™, previously involved massive quantities of solvents and achieved only 40 percent efficiency (= 60 percent waste products). A new process achieves nearly 99 percent efficiency (counting 19 percent recovery of the by-product acetic acid). It "revolutionized bulk pharmaceutical manufacturing, [and] provides an elegant solution to a prevalent problem: how to avoid the large quantities of solvents and wastes associated with the traditional stoichiometric use of auxiliary chemicals when effecting chemical conversions" (U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics 1998, 12).

Dow Chemical has developed processes using carbon dioxide as the blowing agent for the manufacture of polystyrene foam sheet packaging material, used principally for egg cartons and fast food containers. (The CO_2 is derived from existing sources such as ammonia plants and natural gas wells, therefore making no net contribution to climate change.) The Dow technology replaced some 3.5 million pounds of chlorofluorocarbon blowing agents that previously were used for foam production each year, chemicals that contributed to ozone depletion, global warming, and ground-level smog.

Rohm and Haas Company chemists designed a safer marine antifouling compound. Unwanted growth of barnacles and other fouling organisms on ship hulls costs the shipping industry an estimated $3 billion annually, largely from increased fuel consumption due to hydrodynamic drag. Such waste of fuel obviously contributes to pollution, global warming, and acid rain. The main compounds used in recent decades to poison barnacles have been organotins, which persist in the marine environment and decrease the reproductive viability of aquatic organisms. The company's Sea-Nine™ antifoulant biodegrades far more rapidly than previous compounds—with a half-life in sediment measured in hours (compared with 6-9 months for the tin compounds). Sea-Nine™ does not bioaccumulate, whereas tin can reach concentrations in marine organisms as high as 10,000 times its original concentration in the paint. Because of these advantages, the new compound can be used in much higher concentrations, so it can be more effective and require less frequent maintenance.

The above examples seem to be more the rule than the exception in illustrating what is possible. A "2020 Plan" proposed at a 1998 University of Massachusetts Workshop on the Role of Polymer Research in Green Chemistry and Engineering predicted that within two decades, it should be possible to do the following:

- Replace all solvents and acid-based catalysts that have adverse environmental effects with solids, water-based replacements or other "green alternatives."
- Eliminate nearly 100 percent of emissions in polymer manufacturing and processing, and reduce by more than 50 percent the quantity of plastics placed in landfills.

- Increase energy efficiency by 40 percent or more in the manufacture of polymers.
- Achieve a 30-40 percent reduction in waste (energy emissions, water, and raw materials). (National Environmental Technology for Waste Prevention Institute 1998)

These goals would be approached via research on alternative manufacturing techniques, solventless processes, new coatings and films, and green separation techniques. Workshop participants estimated that the greener processes actually would reduce by 50 percent the development time to produce new polymers, partly by simplifying manufacturing requirements and partly by reducing environmental compliance transactions.

One hears pretty much the same sort of expectation from a small but growing number of those at the forefront of other subfields of chemical R&D. This trajectory in some respects is a continuation of ordinary cleanup of the industry that has been occurring for several decades. Among large Italian chemical firms, for example, between 1989 and 1997, air emissions dropped by 54 percent for sulfur dioxide, 72 percent for particles, 82 percent for volatile organic compounds, and 92 percent for heavy metals. Wastewater effluents likewise declined, but not quite as much (Giuiuzza 1998). In addition to pressure from unionized workers and from government regulators, chemical company executives found that in many instances they could actually save money over the long run by reducing chemical releases—saving money both on raw materials and on waste disposal costs.

The Rise and Institutionalization of Green Chemistry

Among the progenitors of green chemistry is Stanford Chemistry Professor Barry Trost, who first proposed the concept of "atom economy" in 1973. Rather than judging a chemical process successful if it produces usable product at a satisfactory cost, Trost argued that those responsible for synthesizing chemicals should aim for elegant efficiency, for using the highest possible percentage of input atoms in the usable output, ideally leaving zero waste. This seemed a utopian concept when first proposed, but an increasing number of biocatalytic and other chemical processes now are being proposed that achieve outcomes very close to that goal (Trost 1991).

The origin of the term *green chemistry* is not clear. *Environmental chemistry*, a predecessor term in common usage by the early 1980s, did not tackle the redesign of chemicals and chemical production processes at the molecular level; it focused instead on water pollution, stratospheric ozone, acid rain, and other aspects of chemistry *in* the environment. Nevertheless, a growing number of chemists began discussing a great many issues that, in retrospect, can be seen as precursors of the ideas now being advocated under the green chemistry banner; among many other examples were the use of corn starch in the preparation of biodegradable packaging materials, and proposals for using renewable raw materials rather than petrochemicals as feedstocks for chemicals (Dwyer, Lewis, and Schneider 1975; Glass 1990; Mitchell 1992).

The movement gained a measure of increased legitimacy and perhaps some additional impetus from the Pollution Prevention Act of 1990, a nonregulatory congressional act. Some administrators at the U.S. Environmental Protection Agency (EPA) believed the act heralded

> a new era in the philosophy and policy of controlling the risks of toxic chemicals. . . . [It] served as guidance by providing a series of approaches to pollution prevention. At the top of this series is "source prevention." In other words, the ultimate approach to preventing problems with toxic chemicals is not to produce such substances in the first place. (DeVito and Garrett 1996, vii)

There is little evidence directly linking the act with subsequent developments.[2] But some observers believe that the EPA's Green Chemistry Program resulted from administrators' desire to carry out what they perceived as a congressional mandate, and it was EPA staff who took the lead in organizing the first symposia explicitly targeted to alternative synthetic pathways at the 1993 and 1994 meetings of the American Chemical Society.

Also perhaps linked indirectly back to the 1990 Pollution Prevention Act was the Presidential Green Chemistry Award competition. Formally announced in March 1995 as part of the Reinventing Government initiative of the Clinton-Gore administration, the award idea was not suddenly dreamed up but rather gestated in the EPA Office of Toxic Substances. Administered by the American Chemical Society and the EPA, the competition receives dozens of nominations annually from industry, universities, and government laboratories for "breakthroughs" in cleaner chemical synthesis, solvent replacement, waste reduction, benign new products, and other aspects of green chemistry. About half the publicity accorded to green chemistry in popular and semipopular publications has centered on these awards, handed out since 1996.[3]

A plethora of terms competed during the early 1990s: clean chemistry, design for environment, benign by design, inherently safe, environmentally benign, and others (Sherrington 1991; Illman 1994; Mittelman et al. 1994; and Miller 1993). Semipopular publications picked up the *green* label before it was widely used at professional conferences, with brief news articles using the term appearing in 1993 in *Science*, the *Wall Street Journal*, *Chemical and Engineering News*, and *Chemical Week* (Illman 1993; Rotman 1993; Amato

1993). With the one obvious exception, these publications were read only by specialists, primarily chemists working in the industrial sector or consulting therein. But by 1995, at least one publication aimed at chemistry educators had introduced the subject (Collins 1995). And ordinary newspapers soon thereafter began to carry brief stories.

A 1994 publication bearing the title "Green Chemistry," published in Belgium, contained papers from a May 1994 European conference. The volume dealt primarily with the economic feasibility of shifting to environmentally sounder production methods for plastics, paper and cardboard, cleaning products, lubricants, and paints (Cornet and Bergans 1994). Between 1994 and 1996, the discourse shifted decisively in the United States: *green chemistry* would be the term of choice.[4] There was continuing resistance in Europe, where Green political parties helped give the term a more radical connotation than some industry executives and their scientific allies found congenial.

The *green* label actually encompassed at least two partially competing approaches, one of which has gained primacy to date. The road not taken was championed by Roger Garrett and Steven DeVito, midlevel scientists and administrators at the EPA, who coedited a 1996 book bearing the title *Green Chemistry* (DeVito and Garrett 1996). They envision the day, far from now, when chemicals are designed so as to not be assimilable into living organisms, or are designed to be easily and quickly metabolized and excreted. Medicinal chemists have long been interested in such mechanisms for pharmaceuticals, but there had been essentially no carryover from medicinal chemistry to industrial, agricultural, and other chemistries.[5] Garrett predicted in 1998 that this was on the verge of changing, proposing, "Organic chemistry textbooks a generation from now will be unrecognizable compared with today's standard texts."[6]

In fact, however, green chemistry conferences and publications to date display little movement toward the difficult, sophisticated approaches outlined by Garrett and DeVito. Instead, the field has come to be dominated by a version of green chemistry closer to chemists' traditional ways of doing things, one based on alternative synthetic pathways, solvent substitution, and other tactics that attempt to circumvent the need for understanding how living organisms metabolize ingested chemicals. This second approach to green chemistry focuses on making chemicals and their production inherently benign rather than attempting brilliant metabolic maneuvers that protect living organisms from chemicals that would be dangerous if not so cleverly designed.

This direction seems to have emerged primarily because industrial chemists are trained to play around with various ways of putting molecules together—and are not trained in much having to do with humans or other living things. Moreover, it is simply easier to avoid using a dangerous chemical or chemical pathway than it is to create a sophisticated, pharmaceutical-like molecular structure that will be quickly metabolized and/or excreted. But social factors also help explain the direction the movement has taken.

The crucial role in catalyzing green chemistry has been that of the director of the green chemistry program within the Office of Pollution Prevention and Toxics at the EPA. Had the job been held by one of those championing safer chemicals in the pharmaceutical tradition, there would have been some chance that the esoteric-chemical route would have been emphasized more equally. But Paul Anastas, the person hired to run the program at the EPA, was himself trained in standard rather than metabolic chemistry, and he chose to nurture the fledgling green chemistry enterprise along the plain-old-chemistry route. In addition to playing a key role in handing out Presidential Green Chemistry awards (U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics 1996), Anastas was in a position to help channel EPA funding toward research projects at Argonne and Los Alamos national laboratories, to help organize and fund conferences, and to edit numerous books based on those conferences (Anastas and Williamson 1996, 1998; Tundo and Anastas 2000; Anastas, Heine, and Williamson 2000; Anastas, Bartlett, and Williamson 2000). He enrolled University of Massachusetts Chemistry Professor John Warner in the endeavor, and the two coauthored the first textbook on green chemistry, published in 1998 (Anastas and Warner 1998).

The movement's leadership has begun to grow beyond the tiny cadre at the EPA. The prestigious Gordon Conferences have held a green chemistry conference biannually since 2000, one indicator of the subject's institutionalization. The National Academy of Science and National Academy of Engineering since 1997 have sponsored an annual international conference, initiated by Anastas but now self-sustaining. And specialized subgroups within chemistry and chemical engineering now are beginning to hold their own meetings (see, e.g., Beary 1999; Rogers 2000).

The American Chemical Society's Division of Education and International Activities, in partnership with the EPA, has begun to disseminate green chemistry educational materials for college and high school students. Goals of the project are to develop an annotated bibliography, a compendium of case studies, laboratory modules, and short courses on green chemistry. The project will connect academic, government, and industry educators; establish communication networks and partnerships; and identify education priorities (American Chemical Society 2004b).

And a variety of organizations and networks with other purposes are beginning to add the term *green chemistry* to their descriptions or key words.

For example, the Global Network for Environment and Technology (GNET), a program of the Global Environment and Technology Foundation (GETF) located in Annandale, Virginia, exists to post contact information, news, press releases, market information, and project information "to assist government scientists and researchers to commercialize innovative environmental technologies" (Global Environment and Technology Foundation 2003). Masters theses and dissertations are being written under the *green chemistry* label or clearly are working within that general realm.[7]

In 2000, Anastas moved to the Office of Science and Technology Policy in the White House, a role from which he gained direct access to President Clinton's science advisor, Neal Lane. Anastas remained in that position in the Bush White House until 2004, when he became head of the Green Chemistry Institute (GCI) within the American Chemical Society. GCI initially was a freestanding not-for-profit created in 1998 at the initiative of several EPA staff members, including Anastas and Joseph Breen, the organization's first executive director.

The GCI is a not-for-profit organization dedicated to environmentally benign chemical synthesis and processing research and education. The organization's Web site includes press releases, a newsletter, conference information, research opportunities, and educational information. The GCI serves as a nongovernmental sponsor of various endeavors, including affiliate institutes in other countries—including India and Taiwan (American Chemical Society 2004a). Additional leaders of the green chemistry movement in and around the GCI have included Sylvia Ware of the American Chemical Society, Tracy Williamson of the EPA, and Denny Hjeresen of Los Alamos.

Conferences in the late 1990s drew relatively little industry participation. More than two-thirds of those attending (many repeats, of course, but more than 1,000 different persons altogether) were from universities or research institutes, and most of the remainder have been government researchers or regulators. The heads of the Austrian and Italian Chemical Manufacturers Associations played significant roles at a 1998 Organisation for Economic Co-operation and Development (OECD) conference in Venice, and there have been industry researchers at every conference, but by no means have they been as numerous or as highly influential as one might have expected.

A possible shift in the balance emerged during the planning of a 2001 international conference in Boulder, Colorado, sponsored by Chemical Research Applied to World Needs (CHEMRAWN), a unit of the International Union of Pure and Applied Chemistry. This conference had more industry visibility, in part because the first person approached to serve as formal chair of the conference, Mary Good, then-president of the American Association for the Advancement of Science (AAAS) and dean of engineering at a major state university, expressed horror at the lack of industry participation in the early stages of the planning process. Rohm and Haas president Mike Fitzpatrick ultimately became conference chair and head of fund-raising, and the organizing committee took great pains to involve industry leaders and researchers. Industrial interest is indicated as well by a growing set of publications oriented toward industrial applications, of which one of the first was a 1998 *Handbook of Green Chemicals* (Ash and Ash 1998), described in a publisher's brochure as "a chemical component [and] green attribute cross-reference manufacturers' directory [for] environmental chemistry—Industrial applications . . . designed as a starting point and guideline in the decision-making process of chemical and material selection."

Although the movement clearly is centered in the United States, it now is spreading internationally. In addition to the international conferences and national green chemistry institutes, research institutes and university curricula are beginning to spring up. For example, the main Chinese technological university, possibly leapfrogging Western universities with greater institutional momentum and fixed capital, has recently opened a new building for a green chemistry initiative. The OECD held its first green chemistry conference in Venice in 1998, several international workshops have been conducted in China, and the chemistry department at the University of Delhi sponsored India's first major international symposium in 2001. Paul Anastas has been a major speaker, organizer, and (until leaving the EPA) funder of many of them. The Royal Society of Chemistry (United Kingdom) began publication in 1999 of a journal entitled *Green Chemistry: An International Journal and Green Chemistry Resource*. The Royal Society also has initiated a Green Chemistry Network, based at the University of York's Department of Chemistry. The aim is "to promote awareness and facilitate education, training and practice of Green Chemistry in industry, academia and schools." The organization's Web site includes a database with links to overseas networks, technology transfer brokerage, links to other organizations and government departments, conferences, workshops, and training courses, educational material for universities and schools, newsletters and books and environmental monitoring journals, and prizes and awards for companies and university researchers.

Social Movement Theory and Green Chemistry

Does it make sense to think of green chemistry as a social movement? When the term *social movement* entered vocabularies early in the nineteenth century, it had a very specific referent: the political-economic struggles of the new industrial proletariat. Even by the 1920s, however, this definition of social movement had become outmoded; the rise of peasant and farmer movements, of fascism and National Socialism, and of independence movements in colonial countries mandated a broader interpretation of the term. In the last decades of the twentieth century, the concept became further modified to include what came to be known as *new social movements*: peace, environmentalism, feminism, gay liberation, and civil rights. Whereas the original definition obviously would not apply to upper-middle-class professional chemists, this expanded understanding of social movement may have room for experts who interact with some coherence for reform aims.

To probe the matter, we draw selectively on analytical tools from social movement studies, particularly the concepts of identity, resources, strategic choices, and mobilization. First, however, what is a social movement? Sociologists use the terms *social movements*, *social movement organizations* (SMOs), and *challenging groups*. Political scientists speak of collective action, citizens' movements, pressure or interest groups, and nongovernmental organizations (NGOs). Anthropologists refer to movements of change, cultural movements, and adaptive movements. Most treatments of these topics converge in dealing with "people mobilizing themselves and other resources to change other people, social structures, and social relations using means which may be unconventional for ends which may include the radical" (Breyman 1998, 19).

Based on this definition, the network of researchers and administrators described above as green chemistry practitioners might be seen as an "elite movement." This is not "elite" in the sense of power elite but merely indicates that if green chemistry is a social movement at all, it clearly is not a *mass* movement. The range of green chemistry activities to date is limited to changing the ways in which chemicals are designed and manufactured, the province of a relatively small, highly trained body of experts (and the managers to whom they report). There is so far no public education campaign targeted at changing the way citizens think about the role of chemicals in their lives. Compare this to the work of antinuclear power or weapons activists who sought to alter the broad public understanding of nuclear power generation and nuclear deterrence. Or consider the intensive public education efforts of feminist or civil rights movements, which sought to transform common understandings of gender or racial justice. Instead, green chemistry advocates aim their educational efforts at their professional peers. Green chemists do not appear interested in constructing a mass movement that would enroll nonchemists.

Social movement organizations, especially early in their careers, spend considerable time discussing their identity. Identity definition builds a cohesive sense of purpose, providing ideological adhesive to hold the members together throughout their campaign: Who are we? What is our mission? What unique analysis or skills do we bring to the struggle? Our research indicates debate among reform chemists and engineers as to what to call themselves. Green chemists are united in seeing themselves as advancing the values of health, safety, and sustainability—and decidedly do not perceive themselves as participants in chemical industry "greenwashing." Of course, they may be mistaken, but the Synthetic Organic Chemical Manufacturers Association and other usual industry lobbying groups are at the periphery rather than the center of the activities, and our sense is that much of what is occurring appears to be a genuine response from within the ranks of chemists and chemical engineers to address the role their professions play in environmental degradation and threats to human and ecosystem health. Although not adopting the label "crusaders," green chemists clearly see themselves as parties to the conscious evolution of sustainable societies.

Green chemists have, as we have seen, considerable resources at their disposal. They have developed the essential tools of communication and institutionalization. There are professional associations, conferences, books, and a journal. They have not yet tried to recruit nonchemists to their cause, nor have they sought to politicize their work, but have concentrated on achieving acceptance within elite technoscientific institutions (Gordon Conferences, AAAS, and so on) and the quiet embrace of industry. It may be difficult for outsiders to imagine the widespread adoption of green chemistry without broader participation and the antagonism that tends to accompany it, but one does not hear even quiet speculation about such matters among green chemists. Other elite movements have formed broader coalitions with nonspecialists, including the Progressive Era physicians who first formed the American Medical Association around public sanitation issues, as well as the nuclear physicists and others who came together after World War II to publish the *Bulletin of Atomic Scientists*, sponsor Pugwash Conferences, and otherwise work for disarmament and peace.

The leadership of any movement, mass or elite, faces choices about strategy, tactics, goals, and mobilization (recruitment, training, and logistics). Among the strategic choices are the following:

- Focus on a single issue, or make multiple demands?
- Make radical demands, or pursue only moderate goals?
- Seek to influence existing elites, or attempt to replace them?[8]
- Political-governmental action, or social-cultural action?
- Short-term achievements, or returns measured in terms of decades or generations?

Green chemists make what might be called single-issue demands, if they are indeed demands at all, given the way we normally understand the term in social movement studies. Movements must choose between "opting into the power structure and opting out, that is, using the movement to make a symbolic statement of dissent from the larger political system" (Solo 1988, 180). Clearly, reform of chemical manufacturing is a "demand" that does not challenge the political-economic status quo. Instead, it might be seen as system functional, a means for those currently in positions of power to defend their status against those who might challenge it on environmental health grounds. Green chemistry is undoubtedly aimed at influencing elites rather than replacing them, via what might be seen as cultural action aimed at an elite audience. It assumes that its preferred reforms are possible within the parameters of current power relations. Green chemists assume that their cause can flourish within the halls of power; rational arguments and scientifically sound pilot projects are presumed sufficient to overcome standard operating procedures, industry's sunk capital invested in brown chemical plant and equipment, and other aspects of technological inertia.[9] Although each change that industry actually makes may have immediate environmental benefits, the low-key, research-oriented approach pursued by most green chemistry advocates promises widespread impact only over the course of several decades.

The goals of green chemistry advocates appear on one level as radical, and on another as quite mild. They appear far-reaching in light of current chemical industry practices. Green chemists have a long way to go before the rest of the profession, within industry and universities, can be "greened." At the same time, reforming chemical designs and processes might appear to some as a relatively small step along the path toward sustainability.

A related choice facing any social movement's leaders and members is whether to remain "polite," to engage in protest, or to move toward violence. Most recent social movements have engaged at least partly in protests, which can take one or a combination of four styles: symbolic, noncooperation, intervention, and alternative institutions (Lofland 1985, ch. 12). Green chemists eschew the first three action forms, choosing as they do to change the internal practices of their own profession, which arguably constitutes an unusual approach to establishing an alternative institution. Alternative institutions are a form of "positive intervention": the establishment of "new behavior patterns, policies, relationships, or institutions which are preferred" (Sharp 1973, 357). This historically has been perhaps the most serious and weighty form of movement action, normally involving processes of withdrawal, refusal, and construction—none of which seems, on first inspection, to characterize our polite green chemists.

On reflection, however, this may be an apt characterization of what we are observing among chemists, for their newfound belief that chemicals and chemical production can be benign clearly is a major shift in thinking from the benefits-outweigh-costs defense offered by the chemical industry starting with the attacks on Rachel Carson. And social movement scholars see such a change in mindset as the first step in constructing an alternative institution. The next step normally is construction of the alternative institution, but in the case of green chemistry, the external structure of the profession need not change: what is institutionally new is not some reform or revolution in a power structure, but a shift in the molecules, synthesis pathways, and other chemical materials and processes with which chemists, chemical engineers, their managers, and ultimately consumers work. This would not be an institutional change in the sense that political scientists normally use the term, but the resulting institution obviously could be quite different in the sense that anthropologists or sociologists of the future may come to describe the practice of chemistry in society.

What about the mobilization of green chemists' time and energy? Does that fit at all with the typical movement pattern that "has to be constructed and has to carve out a career in what is practically always an opposed, resistant, or at least indifferent world" (Blumer 1957, 147)? Gamson defined mobilization as "a process of increasing the readiness to act collectively by building the loyalty of a constituency to an organization or to a group of leaders"; it "is part of an organizing process that precedes specific efforts at influence" (Gamson 1975, 15). For Tilly, mobilization referred to the process by which challengers gain collective control over resources that make collective action possible (Tilly 1978, 54).

Mobilization has two primary components: (1) the creation of commitment, and (2) the activation of commitment. Commitment or dedication to a cause includes a willingness to take risks or experience discomfort or deprivation. Commitment is created and maintained dynamically via interactions of leaders, organizational staff, ordinary participants, and sometimes clients or constituents. Essential to creating commitment is considerable agreement regarding the nature of a problem, who is responsible for it, and what can be done about it. Also essential are the recruitment of activists and the gathering of other resources. This often occurs during attempts to educate policy makers and the public, as a result of sparring with antagonistic pundits and spin-doctors. One barrier to the creation of commitment is inertia—often partly a consequence of ignorance, apathy, or fatigue. Another barrier is the social control exerted by the dominant system—via coercion, law, suggestion, praise, ridicule, and reward.

Sufficient commitment has been created to form a growing network of polite green chemists willing to work within the system, but virtually none is interested in oppositional tactics common to most social movements. Most are content to proceed slowly and methodically, doing scientific research and teaching as usual—albeit with content that differs in important ways from what their field's mainstream still is doing. New participants who are recruited via the conferences, publication outlets, graduate fellowships, and awards hardly even know they have been recruited—because the activities are natural extensions and modifications of normal professional activities. Green chemistry outreach efforts thus are distinctly low key in comparison with movements that target masses of people. As an elite movement, green chemistry has received some support and recognition from government agencies; but the technological momentum of brown chemistry poses a significant obstacle to the success of the international green chemistry network.

Once commitment has been created, it can be activated—moved from consciousness to action. The activation of mass commitment tends to occur when three preconditions are met: "(1) problems that encroach directly on peoples' lives, (2) catalytic events, and (3) education and propaganda. Hard and shiny objects like nuclear missiles or nuclear power plants are ideal means around which to rally people. Generally, the more tangible the problem, and the graver the threat it is perceived to pose, the more readily organizers can activate mass commitment" (Breyman 1998, 113). In the green chemistry case, the problems are defined as important first and foremost for chemists and engineers themselves, so those championing the endeavor are looking to activate the commitment of chemical professionals rather than the public or governmental office holders. The Green Chemistry Institute and other sponsoring organizations have not to date defined "the problem" as a public matter requiring government intervention or even broad public discussion. One can easily imagine environmental movement entrepreneurs providing a very different interpretation of the problem, one that would dramatically increase its relevance for a much wider public.

Such a transition would be facilitated by some catalytic event that would create either opportunities for movement organizers themselves to expand the sphere of action or opportunities for environmentalists presently outside the green chemistry movement to seek to influence or even appropriate it. Catalytic events are not such in and of themselves, of course, but need to be interpreted, cast in a light useful to aid mobilization. The Bhopal disaster and other much smaller chemical plant incidents could have been interpreted as calling for fundamental changes in the chemical industry; but no groups combined sufficient expertise and credibility with adequate resources for publicity and mobilization, and with the ideology and other motivation, to turn chemical disasters/incidents in a direction that contributed to the mobilization of nonspecialists for the green chemistry movement. Perhaps the periodic green chemistry conferences and awards serve as regular, if very small, catalytic events that organizers hope will slowly lead to the overall greening of chemical professionals and then, indirectly, to benign chemicals in society at large.

The informational and rhetorical tools used by organizers for the creation of commitment are also necessary for the activation of commitment. Shared understandings about the nature and extent of a problem, together with ideas about it, are essential for building commitment, attracting activists and other resources, and moving citizens to act. It is necessary to educate the public to rouse it to action. Propaganda—polemical communications designed to generate action—is necessary because if movement organizations did not work to construct reality and to counter social control attempts by public and private authorities, commitment created might not become commitment activated. As discussed above, green chemists have concentrated on educating other chemical professionals about the benefits of their new approaches, not on educating the general public. Green chemists have not yet shown interest in engaging in polemical battles with defenders of the status quo. These consist most obviously of executives in the chemical industry, because essentially none of them would favor scrapping brown chemical plants prior to the end of their useful lives. Allied with industry, unwittingly or half-wittingly, is the vast majority of elected and appointed government officials in the sense that they are failing to provide either legal mandate or tax credits for the shift to green chemistry. Added to this formidable coalition are several billion consumers who with every purchase unknowingly "vote" for keeping old chemical plants and their outdated processes going.

Green Chemists as Environmental Activists?

What are some of the possibilities and problems that political progressives would face in trying to cooperate with green chemists? Can one imagine scenarios in which an elite green chemistry movement grows to include professional environmental activists and their organizations and supporters, activists who would expand the sphere of discussion and conflict?

The first and most obvious difficulty is that many of the technoscientists are suspicious of "politics" and opposed to further government regulation of the chemical industry. This is in keeping with the tenets of political conservatism, widely embraced among chemical engineers—although less so among chemists, especially those who work in universities. But even some of the moderates and liberals are concerned that elected officials may turn the issue into a matter for partisan grandstanding. Then, they project, industry executives will react defensively and will downplay the prospects for benign chemicals because they will be afraid of being legally required to sunset existing chemical processes and products. And then, if environmental and consumer groups and the news media become activated, many scientists fear that the whole issue could degenerate from what the technical types tend to call "rational" discussion into "emotionality" and even "extremism."

A second difficulty is that the vast majority of those practicing green chemistry speak in a language that is indecipherable to ordinary people. Very few environmentalists know anything about monomers, polymerase chain reactions, covalent bonds, or anything else about organic chemistry. A few of the chemical experts are adept at translating their knowledge for lay audiences, but this is a distinct minority. Even those who are good at it have other priorities: if in universities, they are busy in the laboratory, in winning grants, and in traveling the conference circuit; and if in industry, their priorities are winning budgets, dealing with subordinates and superiors, and trying to balance profit making with research productivity. And they have trade secrets to protect.

It would be reasonable to expect the major environmental groups to serve a translation function between the experts working at the forefront and the rest of us. Yet the Sierra Club, Environmental Defense Fund, Friends of the Earth, and Greenpeace actually have only a handful of staff members who truly work at the interface of chemistry and politics. As of this writing, so far as we know, no environmental group anywhere in the world is directly and unambiguously advocating green chemistry. For a brief period in the mid-1990s, Greenpeace attempted to build a coalition to seek an across-the-board phase-out of chlorinated chemicals. Had the move caught on, it obviously might have greatly stimulated development and production of benign-by-design chemical alternatives. However, Greenpeace quickly backed down in the face of vociferous opposition from industry executives and the mainstream university chemists who tend to ally with business. Hence, although many environmental organizations advocate stricter controls on a handful of especially dangerous chemicals such as methyl mercury, the overwhelming majority of environmental Web sites and printed materials fail to discuss the emerging potentials of green chemistry.

Moreover, very few science journalists who have working familiarity with chemistry. If one reflects on the types of articles appearing in such semi-popular venues as *The New York Times* "Science Times" section, the articles deal overwhelmingly with biology and with advances in computing. Physics, archaeology, and astronomy probably are next. Chemistry articles are few and far between.

Another barrier to the movement is one found in most social institutions: there is in chemistry, chemical engineering, and the chemical industry considerable cognitive, institutional, and other inertia standing in the way of the transformation. This is about as true in universities as it is in industry and government, as for example in the commonplace assertion heard from chemical engineering professors that "there is just no room in the curriculum" to give substantial attention to greener chemical processes.

On the other hand, concern for students' and chemical plant workers' safety now is on the minds of chemical researchers and chemical industry executives in a way it simply wasn't a few years ago. We have spoken with a number of middle-aged chemists who reported washing their hands in dangerous solvents in graduate school and thinking nothing of it. It probably is an exaggeration to say, as one industry chemist did, "Every chemical company has to be looking at its product line and wondering, 'What could we do differently to protect the environment?'" But the overstatement makes the point that environmental issues in some guise are not too far from the minds of executives in larger firms in more affluent societies. And an increasing number are gaining experience in finding that changing chemical production processes actually can reduce costs for raw materials and for waste management, transportation, and disposal.

So the way is at least partly open, but the myriad promising ideas may come into use more slowly and less systematically than would be environmentally sound and technically feasible—unless environmentalists figure out how to support green chemistry without giving up their justified concerns about the chemical industry. One simple and underused strategy is that of "jawboning," the process by which public officials encourage business executives to take actions in the public interest. This can carry the implied or stated threat of being followed up with regulation if businesses do not comply. The Swedish Chemicals Inspectorate, for example, has mandated a phase-out of certain toxic chemicals in manufacturing and has some 250 on an "observation" list that pretty clearly are destined to be banned. Officials in other nations might credibly threaten to emulate Sweden in this regard.

What else might progressives seek to do to accelerate the greening of chemistry and chemical engineering? Progressive, public media, and environmental journalists might report on developments in green chemistry for their newscasts and periodicals. Environmentalists might participate in green chemistry conferences and invite green chemists to their own research-oriented conferences. Socially responsible investment firms and environmental health advocacy organizations might begin tracking and rewarding, in their own way, firms and researchers experimenting with greener processes and products. Green chemists at universities might enlist the support of the broader campus greening movement for their own curriculum reform efforts. Enlightened corporate managers might see to it that green chemical work at their firms is supported and makes it into annual reports and onto company Web sites.

Conclusion

Have we pushed the social movement theme a bit too far? Consider one leader's perspective: "The moment a chemist puts pencil to paper to design the way a chemical product will be made, he is also intrinsically deciding whether toxic chemicals will be used or generated, [and] what the waste disposal costs will be," Paul Anastas told the first green chemistry symposium, held at the 1993 meeting of the American Chemical Society. One might rephrase that to say that chemists in certain respects are humanity's representatives in making decisions fraught with public consequences for human health and environment. If some of those with technical training in chemistry are trying to convince others to make changes in humanity's "policy" for chemicals, it is difficult to miss the parallel with other aspects of the environmental movement in which some persons and organizations try to convince others to change environmental policies and outcomes.

More generally, what does the green chemistry case have to teach about the social (re)construction of technological innovation and the roles therein of technical experts? We wonder if what seems like an unusual situation in chemical industry may in fact be more common than most observers of technological society have recognized. Fears about technocracy received considerable attention at various points in the past century and more, but most scholars and progressive activists have not found the concerns very compelling compared with all of the other difficulties standing in the way of greater democracy, fairer treatment of have-nots, and improved environmental sustainability. Policy intellectuals clearly have seized some of the discourse turf, and that is a worry for democratic theorists (Dahl 1990; Fischer 2000). And the combination of technoscientific, economic, and other analytic methods now deployed in policy debates sometimes make it more difficult for ordinary people and even interest group activists to participate knowledgeably and influentially in some methods-intensive policy disputes (Laird 1990, 1993).

A few social thinkers go much farther to argue that a kind of soft technological determinism or momentum plays a very substantial role in reshaping technology over time (Sclove 1995; Smith and Marx 1994). Although nothing is done without humans and their organizations being involved, of course, the constraints and incentives within which key players work are partly or largely ordained by previous sociotechnical circumstances coupled with emerging technical potentials. The physicists, molecular biologists, and nuclear engineers obviously play necessary roles in bringing the new technologies into being; but if any one of them chose not to facilitate the innovation, others would step forward to do so (Woodhouse 1997).

There is merit in such structural interpretations. But most observers of science and technology perceive a good deal more agency in operation than is highlighted in theories of technological momentum. Lots of technical experts are developing practices, creating instruments and techniques, and making choices that could have turned out quite differently. Yet few STS (science and technology studies) scholars draw what seems to us an obvious inference: if technology is in certain respects legislation that shapes everyday lives of millions of persons, then among the principal "legislators" are certain technoscientists who lead the way in developing the technical potentials and shaping them into technological innovations that can be sold and used (Winner 1977). Business executives, customers, and government officials, among others, also participate in this process, of course, but there are not many major innovations that come into being with technoscientists playing a leadership role.

In that sense, green chemistry may be closer to business-as-usual than to a radical departure. (We actually think it is somewhere in between.) What is clearly unusual is that the green chemists are leading in directions that in some respects are more progressive than what many environmentalists are seeking. That suggests the possibility that environmental organizations and their supporters may wish to inquire seriously into prospects for cooperation with green chemists in pushing faster and harder toward a benign chemical regime. Whether green chemistry to date constitutes the elite movement we have been investigating in this article is less important, after all, than whether those with expertise in benign chemical synthesis have insights that the rest of the environmental movement ought to be pursuing more diligently.

Without a deeper appreciation of the potentials for green chemistry, environmentalists run the risk of forever fighting symptoms instead of working to change root causes of environmental problems. And without the broader social thinking, public discussion, and political action of the larger environmental movement, there is a clear and present danger that green chemists may unintentionally contribute to shoring up the status of the chemical industry as a realm protected from searching public scrutiny. In many nations, there has been a swing away from regulation and toward "cooperation" between government and industry. "Co-optation" has just about the same spelling and in some cases just about the same meaning. So environmental partisans probably ought to worry when public official after public official, and academic scientist after academic scientist, speak of "forming research agendas based on industry needs," "industry + university = new science and new process," "environmental improvement and economic growth are not in conflict," and so forth.

Negotiation often makes more sense than litigation, of course, and sometimes is superior as well to governmental mandates that encourage evasion and foot-dragging. But blindly relying on business executives and their technoscientific employees and consultants to serve public purposes is what brought about the twentieth century's brown chemistry. And some of the most reliable understandings from economics and political science concern market failures and shortcomings, together with well-documented warnings concerning excessive privileges accorded the business sector (Lindblom 1977, 2001). Thus, green chemistry may be too important to be left to those with technical training, even though they have started to move in very promising directions that have the potential to fundamentally rearrange humanity's use of molecular design. It may be time for participants in the broader environmental movement to begin working with relevant experts to propose credible tax incentives, regulations, and mandates; foster public debate; and begin to use the state's legitimate coercive role to reshape innovation in line with public purposes—but to do so a good deal more deftly than some of the governmental steering of technoscience in the past century.

Notes

1. A quick introduction to the subject is found in the field's first text (Anastas and Warner 1998). Among the first books on the subject were DeVito and Garrett (1996) and Anastas and Williamson (1996).

2. Complicating the effort to trace the influence of the 1990 act is the fact that some EPA staff and their programs had already begun to use the "pollution prevention" language. See, for example, U.S. Environmental Protection Agency, Office of Research and Development (1990).

3. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics (1996, 2). Current "Green Chemistry Challenge Partners" include the American Chemical Society; American Petroleum Institute; BF Goodrich; Chemical Manufacturers Association; Council for Chemical Research; Dow Chemical; Dow-Corning; DuPont; Eastman Kodak; Environmental Commissioners of the States; Gulf Coast Hazardous Substance Research Center; Los Alamos National Laboratory; National Research Council; Polaroid; Rochester Midland; Society of the Plastics Industry; Solutia; the University of Massachusetts, Boston; the University of South Alabama; the U.S. Department of Energy; and the U.S. Environmental Protection Agency.

4. Compare Anastas and Farris (1994) with Anastas and Williamson (1996).

5. For one very early expression of intent, see Baumel (1984).

6. Except when otherwise noted, all quoted material is drawn from interviews conducted by Woodhouse during 1998-2000 with government officials, university researchers, chemistry

students, corporate executives, and interest group representatives—primarily from the United States but also from Britain, Denmark, Germany, Italy, Japan, Sweden, and the Netherlands.

7. For example, the Chemical Engineering Department at New Jersey Institute of Technology in 1999 awarded a MS for work on "Sustainable green manufacturing of energetic materials."

8. The first three strategic choices are discussed in Garner (1977, 230).

9. On technological momentum, see Hughes (1983).

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